Response to Community Comment 1 – Dr. Giacomo Medici

Dear Dr. Giacomo Medici,

We thank you for taking the time to review our work and provide helpful and supportive comments. We have addressed your comments below in blue. As more progress is made towards global snowpack monitoring, we hope that better connections are built between the fields of snow hydrology and hydrogeology. We believe your comments led to a better referenced and more representative introduction and a stronger conclusion.

Sincerely,

Randall Bonnell, on behalf of co-authors

General comments

Paper of large impact that can be highly cited in the future. Indeed, lots of research is focusing these days on remote sensing and the role of the snowpack in hydrology. See below my specific comments for the Discussion.

Specific comments

Abstract

1. Lines 30-40. Specify in the abstract the spatial scale. How much is the area large? The idea is to provide the observation scale in the abstract to enhance clarity.

We agree, a sense of spatial scale is critical for placing our work in context. We have revised lines 31 and 33 to include the approximate size of the UAVSAR swath and the approximate sizes of the two field sites.

Introduction

1. Lines 42. "In snow-dominated watersheds, melt from seasonal snowpacks drives streamflow and groundwater recharge". Add recent papers that show the importance of snowmelt on aquifer recharge in snow-dominated watersheds worldwide:

- Tracking flowpaths in a complex karst system through tracer test and hydrogeochemical monitoring: Implications for groundwater protection (Gran Sasso, Italy). Heliyon, https://doi.org/10.1016/j.heliyon.2024.e24663

- Snowpack aging, water isotope evolution, and runoff isotope signals, Palouse Range, Idaho, USA. Hydrology, 9(6), 94, https://doi.org/10.3390/hydrology9060094

Thank you for your suggestion! The reference that we cited (Li et al., 2017) primarily discusses the contribution of snowmelt to streamflow. We agree that including a reference to snowmelt recharge of groundwater would provide better support for our statement. Of the two references suggested, we have chosen to cite Lorenzi et al. (2024) because their findings directly tie groundwater flow to the snowmelt season.

1. Line 50. Summarize the scenario of snow decline in other mountain belts. What about Andes? See below:

- Rapid decline of snow and ice in the tropical Andes–Impacts, uncertainties and challenges ahead. Earth-science Reviews, 176, 195-213, https://doi.org/10.1016/j.earscirev.2017.09.019.

Unfortunately, snowpack development in the Andes is largely limited to glacierized basins and monitoring of snowpacks in the Andes has been extremely limited. Thus, most estimates of changes to Andean snowpacks are highly uncertain. Monitoring of Andean snowpacks is one potential application of the InSAR method that we evaluate in our manuscript.

We have opted to include snowfall projections for the Himalayas as described by Viste & Sorteberg (2015) in line 51.

Line 116. I suggest adding the three to four specific objectives of the research by using numbers (e.g., i, ii, iii).

Thank you for this suggestion. We have revised lines 112–117 to include the number of specific research objectives and to better delineate the sequence of the objectives.

Methods.

1. Line 174. "Along a ~40–60 km stretch with a 16 km swath width". I suggest inserting the link with Figure 1a.

We have revised this line to include a reference to Figure 1a and a citation of the UAVSAR dataset.

2. Line 221. I suggest “key in situ measurements included in this research are:...”

   Accepted.

3. Line 271. “3×3 pixel grid”. Please, specify the size.

   Done.

Results

1. Line 305. “RMSE”, specify the acronym “Root Mean Squared Error” earlier in the manuscript.

   Thank you for catching this. We have revised the first mention of RMSE in the main manuscript (Line 219) to spell out root mean squared error.

Discussion and Conclusion

1. Lines 503-518. Recall the wider implications of your paper that are part of your discussion. Please, do not simply summarize your results in the Conclusion.

   We have adjusted our conclusion to emphasize the utility of the InSAR SWE retrieval methodology as observed in our manuscript. In particular, we described the technique as having promisingly accurate statistical distributions over larger spatial scales, but low correlation coefficients for single InSAR pairs, which suggests caution for SWE interpretation at the single-pixel scale. We highlighted that our manuscript emphasized open study areas and that L-band InSAR applicability below forest cover remains an active question. Finally, we connected our automated station study to the utility of cumulative InSAR SWE retrievals, a requirement for any SWE remote sensing method.

Figures and tables

1. Figure 2. I suggest to make either the boxes for GPR and TLS workflows lighter. The green in the GPR Workflow is too dark for letters in black.

   Thank you for this suggestion. The GPR box color has been changed to a pastel red color.

2. Figure 8. Not very conceptual. Is it necessary in the manuscript? Possible to insert in the Supplementary Material?

We believe that Figure 8 represents a central finding of our study. Coherence is a measure of the similarity between two radar signals. For reference, two radar signals that are perfectly in-phase and have the same frequency and amplitude characteristics have a coherence = 1.0. Coherence degrades as one or both signals moves out-of-phase with the other. Low coherence has been presented as a primary obstacle for using InSAR for snowpack monitoring (e.g., Deeb et al., 2011). We review the processes that cause coherence degradation in the Introduction. Notably, coherence is expected to degrade with increased temporal baselines, which is a primary concern for L-band InSAR ΔSWE retrievals from the upcoming NISAR satellite mission, because NISAR will have a 12-day temporal baseline.

Figure 8a shows that L-band InSAR ΔSWE retrievals can be reliably retrieved even for lower coherences (coherence <0.4), while Figure 8b shows that moderate coherence levels are maintained for the 15-day temporal baseline pair. Thus, Figure 8 supports the application of L-band InSAR ΔSWE retrievals from the NISAR satellite and other upcoming L-band SAR satellites (e.g., the ROSE-L satellite).

References

1. Lines 644-870. Add the relevant references suggested above on the importance of the snowpack in the hydrological cycle.

Done.

References

Deeb, E. J., Forster, R. R., and Kane, D. L.: Monitoring snowpack evolution using interferometric synthetic aperture radar on the North Slope of Alaska, USA, International Journal of Remote Sensing, 32, 3985–4003, https://doi.org/10.1080/01431161003801351, 2011.

Li, D., Wrzesien, M. L., Durand, M., Adam, J., and Lettenmaier, D. P. (2017). How much runoff originates as snow in the western United States, and how will that change in the future?, Geophysical Research Letters, 44, 6163-6172, https://doi.org/10.1002/2017GL073551, 2017.

Lorenzi, V., Banzato, F., Barberio, M. D., Goeppert, N., Goldscheider, N., Gori, F., Lacchini, A., Manetta, M., Medici, G., Rusi, S., and Petitta, M.: Tracking flowpaths in a complex karst system through tracer test and hydrogeochemical monitoring: Implications for groundwater protection (Gran Sasso, Italy), Heliyon, 10, e24663, https://doi.org/10.1016/j.heliyon.2024.e24663, 2024.

Viste, E., and Sorteberg, A.: Snowfall in the Himalayas: an uncertain future from a little-known past, The Cryosphere, 9, 1147-1167, https://doi.org/10.5194/tc-9-1147-2015, 2015.